PRODUCT CLASSIFICATION AND ITS IMPLICATION ON COMPETITIVENESS AND CARBON LEAKAGE

ALUMINIUM

Sean Healy
Katja Schumacher

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Aluminium

Contents

1. Executive Summary ................................................................. 1
2. Introduction .............................................................................. 3
3. Overview of the aluminium sector .............................................. 4
   2.1. Description of the production process ................................ 4
   2.1.1. Primary and secondary aluminium production ............. 4
   2.1.2. Semi-fabricated aluminium production ........................... 6
   2.2. Global production output .................................................... 7
   2.2.1. Primary aluminium production output ......................... 7
   2.2.2. Secondary aluminium production output ....................... 10
   2.3. Emissions ........................................................................ 11
   2.3.1. Emissions from primary aluminium production ............ 11
   2.3.2. Emissions from secondary aluminium production ........... 12
4. Trade flow analysis ................................................................. 13
   3.1. Trade flow differentiated by product ................................. 13
   3.1.1. Aluminium by product ................................................ 13
   3.2. Trade flow differentiated by country /region ...................... 14
   3.3. Trade flow differentiated by product by third country ........ 17
   3.3.1. Aluminium by product by third country ........................ 17
5. Carbon leakage analysis .......................................................... 19
   4.1. Assessment of carbon leakage at the sector level .................. 19
   4.2. Trade intensity and emission benchmarks for aluminium products 21
6. Summary and Discussion ........................................................ 23
7. References: ........................................................................ 26
1. Executive Summary

The impact of the EU Emissions Trading Scheme (ETS) on the competitiveness of European firms has been widely debated between policy makers and industry. It is difficult to ascertain with certainty the extent to which European firms are at a competitive disadvantage, given that trade patterns and investment decisions are the product of a complex mix of factors. However, the European Commission accepts that certain sectors or sub-sectors based upon their trade intensity and value at stake require measures, such as the allocation of free allowances in Phase III, to protect against any competitive disadvantage resulting from their involvement in the EU ETS. The aim of this study is to provide an overview of the production output, specific emissions and trading patterns of the aluminium sector at the disaggregated product level in order to determine whether certain products require special consideration when designing policies to improve the competitiveness of European firms and to prevent carbon leakage.

- **Production output**
  - Global aluminium production is growing again after the recession. The countries driving this global growth appear to be from China and the Middle East, where investments are resulting in increased primary production capacities.
  - In contrast, the EU27 and the USA have seen their share in the global production of primary aluminium decline between 2005 and 2009. However both regions are associated with high recycling rates for secondary aluminium production.

- **Specific emissions**
  - The majority of emissions in the production of primary aluminium originate from indirect sources, which reflects the high electricity consumption associated with the smelting process.
  - Depending upon the carbon content of electricity production specific emissions will be either relatively high in the case of China (i.e. high use of coal in energy mix) or relatively low in the case of Norway (i.e. high use of hydropower in energy mix).

- **Trading patterns**
  - The main export destinations of the EU27 are the USA, Switzerland, China and the Russian Federation. Indirect trading partners have been identified in each of these four markets. Canada (Australia) has a strong trading relationship with the USA (China). Brazil (Kazakhstan) has emerged as a competitor in the Swiss (Russian) market.
  - The EU27 imports considerably more aluminium products, especially those lower down the value chain, than the region exports to world markets. The import market of the EU27 was severely affected by the economic recession.
  - Norway and the Russian Federation have been identified as important trading partners for the import of the unwrought aluminium product. The EU27 exports aluminium plate and foil to the more lucrative US and Chinese markets. However, interestingly the EU27 also exports aluminium scrap to China.
Given the basic hypothesis that trade intensive and energy intensive products are more exposed to carbon leakage risk, the trade intensity of each aluminium product was calculated based on PRODCOM data and was subsequently compared, where possible, to the product benchmarks on specific emissions that were applied in the EU ETS benchmarking exercise. The main findings from the analysis included that:

- Unwrought aluminium is a product that may be particularly exposed to carbon leakage due to its’ high trade and CO₂ intensity benchmark. Equally the low trade intensity and CO₂ intensity of secondary aluminium is less of a concern for carbon leakage.
- Although semi-fabricated aluminium products are also associated with high trade intensities it is expected that the risk of carbon leakage is lower due to the low range of direct emissions and product specialisation.

The study contributes to the on-going carbon leakage discussion in the aluminium sector with the provision of a subset of countries and products that require special consideration in future research. The import of unwrought aluminium by the EU27 from both Norwegian and Russian trading partners demonstrates the value of such an analysis. The import of this energy intensive product from outside the EU27 will only result in carbon leakage if the unwrought aluminium originates from the Russian Federation. This is due to the fact that Norway is a member of the EU ETS and has access to low carbon electricity. In contrast, the carbon content of electricity in the Russian Federation is considerably higher and therefore carbon leakage is potentially an issue that needs to be resolved. The identification of countries and products of interest may allow for more considered policy measures to address carbon leakage risks in the future.

The assessment of the sector’s exposure to carbon leakage is limited by data constraints at the product level with regard to GVA and emissions data. It is acknowledged that the use of emission benchmarks fails to represent actual emissions and therefore the potential cost of carbon pricing for aluminium firms. However, the aim of this paper is to focus attention on where different datasets can improve our understanding of the carbon leakage risk. It is evident from the analysis in this paper that actual emissions data at the product level is urgently required to complete a comprehensive assessment of the competitiveness issues associated with carbon pricing.
2. Introduction

Aluminium is the second most widely used metal in the world after steel (IAI, 2011), with applications including transportation, packaging and construction. The useful properties of the metal (i.e. strong, durable, flexible, lightweight, corrosion-resistant, completely recyclable, a good conductor of electricity and heat), means that aluminium products are a highly traded commodity and global demand is only set to increase further in the future. Given that the production of aluminium is also associated with energy intensive processes; there is a genuine anxiety within Europe that the sector will be increasingly exposed to competitiveness concerns through indirect, electricity-based cost increases as a consequence of the EU ETS. It is important to acknowledge that European producers of aluminium are constrained by the price of aluminium being set globally by the London Metal Exchange (LME), which prevents firms from raising prices to compensate for increased production costs.

The extent to which the additional carbon costs of the EU ETS reduce the competitiveness of European aluminium producers is uncertain. On the one hand, production costs (i.e. materials, energy, labour, capital costs) by region varied considerably prior to the introduction of the EU ETS and the additional cost of carbon in Europe may be less significant than, for example, the impact of subsidised energy prices in third countries. On the other hand, long-term electricity contracts may have initially protected firms from the adverse impacts of the EU ETS and these aluminium producers may be exposed to carbon leakage when the terms of these electricity contracts change in the near future. According to the EAA (2011) the measures proposed by the European Commission to prevent effects on competitiveness and carbon leakage are insufficient as free allocation of emission allowances only applies to direct emissions and no compensatory mechanisms have yet been confirmed for the CO₂ cost pass through in electricity prices. The impact of the EU ETS on the competitiveness of the aluminium industry in Europe is a highly contentious debate, which is currently uncertain.

Given the future impacts of CO₂ pricing, the focus of this study is to provide an overview of the aluminium sector at the disaggregated product level to determine whether certain products require special consideration when designing policies to improve the competitiveness of European firms and to prevent carbon leakage. Following a brief description of the production process of aluminium products in Section 3, the identification of key trading partners with the EU27 and the aluminium products traded will be outlined in Section 4. The trade intensity and value at stake indicators previously applied by the Commission to compile a list of sectors ‘deemed to be exposed to a significant risk of carbon leakage’ are summarised in Section 5 for the aluminium sectors and attempts are made to re-calculate the indicators at the disaggregated product level. The main findings from the study and the data gaps that need to be addressed for further research are discussed in the conclusion in Section 6.
3. Overview of the aluminium sector

Aluminium is produced via the primary or secondary route, which are both associated with different raw material and fuel inputs and therefore different specific emissions. The production process is described in the following chapter for primary aluminium, secondary aluminium and aluminium products with additional information also provided about the annual production and where possible capacity rates for a selection of third countries competing with the EU27 on world markets along with also regional information on specific emissions associated with aluminium production.

3.1. Description of the production process

3.1.1. Primary and secondary aluminium production

The two main processes involved in the manufacture of primary aluminium include the Bayer process to produce alumina and the Hall-Heroult process, which subsequently reduces the alumina in a primary smelter via electrolysis to produce aluminium. A simplified illustration of these production processes along with the initial extraction of bauxite for the Bayer process and the production of anodes for the Hall-Heroult process are all provided in Figure 1.

Figure 1 Flow chart of the aluminium production process

Source: Öko Institut (2011); adapted from Phylipsen, et al. (1998)
Following the extraction of bauxite, which is considered to be a process outside of the system boundary in aluminium production, the raw material is converted to alumina via the Bayer process. The Bayer process is very energy intensive consuming on average 13% and 85% of total electricity and fuel use for the production of primary aluminium respectively (Worrell et al., 2007). The Bayer process involves the following key steps in the bullet points below:

- **Digestion**: Bauxite is ground and slurried into a caustic soda (NaOH), which is then pumped into large pressure tanks called digesters. The sodium hydroxide reacts with the alumina minerals to form soluble sodium aluminate (Menzie et al., 2006).
- **Clarification**: The soluble sodium aluminate formed by the digestion step is then depressurized and coarse sand is also removed from the solution (Menzie et al., 2006).
- **Precipitation**: Alumina seeds are added to the solution from the clarification step to facilitate the precipitation of larger agglomerated alumina crystals (Menzie et al., 2006).
- **Calcination**: The agglomerates of soluble sodium aluminate (NaAlO\(_2\)) are then heated in rotary kilns, which may exceed 960 °C, therefore driving off the chemically combined water, leaving a commercial-grade alumina (Menzie et al., 2006).

The Hall-Heroult process electrolytically reduces the alumina product to aluminium in a primary smelter. The process involves the use of electrolytic cells, whereby the alumina is reduced in a fluorinated bath of cryolite under high intensity electrical current. The electrolysis of the alumina product is energy intensive (49 GJ/t) and the process accounts for the majority of electricity consumption in the production of primary aluminium (Table 1). Anodes are considered to be critical to the reduction of alumina. Firstly anodes carry the electric charge to the cryolite (aluminium solvent) in the reduction cell, which is necessary to drive the reaction. Secondly anodes ‘provide the carbon (which causes the anode to be continuously consumed) for the reduction reaction that strips the oxygen from the alumina and removes it to the atmosphere as carbon dioxide’ (Menzie et al, 2006). Following the electrolysis, the molten aluminium is then transported from the reduction cell to the cast house, where it may be alloyed and then cast into ingots (Menzie et al, 2006).

<table>
<thead>
<tr>
<th>Process</th>
<th>Input</th>
<th>Primary Aluminium [GJ/t]</th>
<th>Secondary Aluminium [GJ/t]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alumina Production</strong></td>
<td>Fuel [Digesting]</td>
<td>12.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fuel [Calcining Kiln]</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td><strong>Anode Manufacture</strong></td>
<td>Fuel</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td><strong>Aluminium Smelting</strong></td>
<td>Electricity</td>
<td>49.0</td>
<td></td>
</tr>
<tr>
<td><strong>[Electrolysis]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ingot Casting</strong></td>
<td>Electricity</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>70.6</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Source: Worrell et al. (2007)
The production of secondary aluminium relies upon the use of recycled aluminium scrap that is either generated at the smelter and fabrication plants (i.e. new scrap) or collected post consumption (i.e. old scrap). Depending upon the source of the scrap material it may be necessary to pre-treat the metal (i.e. sorting, shredding and cleaning) in order to promote more efficient melting in the smelting and refining steps of the process. Secondary producers are often distinguished into two categories:

- **Remelters**: produce wrought alloys from mainly clean and sorted wrought alloy scrap which often supply rolling mills and extruders (Luo and Soria, 2007).
- **Refiners**: produce casting alloys and deoxidation aluminium from scrap of varying composition, and are able to add alloying elements and remove certain unwanted elements after the melting process (Luo and Soria, 2007).

The majority of the furnaces used in the melting process can be categorised as either being high emitting or low emitting. High emitting furnaces such as reverberatory melting furnaces are usually deployed to process old scrap, which is often contaminated. The standard reverberatory furnace is the most common technology used in secondary aluminium production and is most often deployed to process large volumes of smaller size aluminium scrap. Alternatively low emitting furnaces such as induction furnaces can be used to process clean scrap only from new sources such as primary aluminium production (Luo and Soria, 2007).

### 3.1.2. Semi-fabricated aluminium production

The two main processes involved in the manufacture of aluminium products involve either the rolling or extrusion of unwrought aluminium following the casting process. A simplified illustration of aluminium products manufactured by these semi-fabricated processes is outlined in Figure 2. The production of aluminium plate, sheet, foil, wire, rod and bar products are all manufactured by pressing or rolling ingot (i.e. slab) and extrusion ingot (i.e. billet), which are cast from molten primary or secondary aluminium by the ingot casting process. The unwrought aluminium is then manufactured into semi-finished aluminium products by mainly rolling and extrusion processes.

Aluminium sheets, plates and foil are manufactured using the rolling process, which involves rolling ingot (i.e. slab) passing through a hot rolling and a cold rolling mill. As a consequence of the rolling process, the aluminium becomes thinner and longer. The energy intensity associated with the hot and cold rolling of aluminium products is 0.62 and 0.64 kWh/kg of rolled product respectively (Choate and Green, 2003). According to the Aluminium Association (2011) the thickness of the aluminium following the rolling process determines whether the product will be a plate (i.e. 0.250 inch thick or more), a sheet (i.e. 0.249 to 0.006 inch), or foil (i.e. 0.0079 inch or less). Aluminium bars, rods, tubes and pipes are often produced using the extrusion process, which involves the forcing of aluminium billets under pressure through a metal die. The extrusion process provides designers of aluminium products with greater flexibility as profiles can be custom designed to exact specifications. The energy intensity of the extrusion process is higher than the previously described rolling process as it requires 1.30 kWh/kg of extruded product (Choate and Green, 2003). Aluminium wire can also be produced using the extrusion process.
3.2. Global production output

3.2.1. Primary aluminium production output

The global production of primary aluminium in 2009 was 37.3 million metric tonnes with a world smelter capacity of 48.8 million tonnes (USGS, 2010a). Table 2 shows that in 2009 China produced 12.9 million metric tonnes of primary aluminium, which is equivalent to 35% of global production (Figure 3). The Russian Federation produced approximately 3.8 million metric tonnes of primary aluminium in 2009, accounting for 10% of global production (Figure 3). Furthermore, in 2009 the primary aluminium produced in the EU27 and the USA represented 7% and 5% respectively of global production. The global share of primary aluminium production between the main producing countries or regions has changed over time. Firstly it is noticeable that China has experienced a considerable growth in its share of primary aluminium production from 24% in 2005 to 35% in 2009 (Figure 3). The production of primary aluminium in the United Arab Emirates has increased by approximately 40% between 2005 and 2009 and therefore the country’s share of global production has increased from 2% to 3% in this period. In contrast, the EU27 and the USA have both seen their production share decline by 3 percentage points between 2005 and 2009.
Table 2  Production of primary aluminium by country or region during the period 2005 to 2009

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EU27</td>
<td>3,264</td>
<td>3,064</td>
<td>3,111</td>
<td>3,045</td>
<td>2,524</td>
</tr>
<tr>
<td>China</td>
<td>7,800</td>
<td>9,360</td>
<td>12,600</td>
<td>13,200</td>
<td>12,900</td>
</tr>
<tr>
<td>USA</td>
<td>2,481</td>
<td>2,284</td>
<td>2,554</td>
<td>2,658</td>
<td>1,727</td>
</tr>
<tr>
<td>Norway</td>
<td>1,372</td>
<td>1,331</td>
<td>1,357</td>
<td>1,358</td>
<td>1,130</td>
</tr>
<tr>
<td>Russia</td>
<td>3,647</td>
<td>3,718</td>
<td>3,955</td>
<td>4,190</td>
<td>3,815</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>722</td>
<td>861</td>
<td>890</td>
<td>948</td>
<td>1,010</td>
</tr>
<tr>
<td>Iceland</td>
<td>272</td>
<td>320</td>
<td>398</td>
<td>787</td>
<td>785</td>
</tr>
<tr>
<td>South Africa</td>
<td>846</td>
<td>931</td>
<td>914</td>
<td>811</td>
<td>809</td>
</tr>
<tr>
<td>Australia</td>
<td>1,903</td>
<td>1,932</td>
<td>1,957</td>
<td>1,974</td>
<td>1,943</td>
</tr>
<tr>
<td>Canada</td>
<td>2,894</td>
<td>3,051</td>
<td>3,083</td>
<td>3,120</td>
<td>3,030</td>
</tr>
<tr>
<td>India</td>
<td>942</td>
<td>1,105</td>
<td>1,222</td>
<td>1,308</td>
<td>1,400</td>
</tr>
<tr>
<td>Brazil</td>
<td>1,499</td>
<td>1,605</td>
<td>1,655</td>
<td>1,661</td>
<td>1,536</td>
</tr>
<tr>
<td>Mozambique</td>
<td>555</td>
<td>564</td>
<td>564</td>
<td>536</td>
<td>545</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>106</td>
<td>127</td>
</tr>
<tr>
<td>Japan</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>3,696</td>
<td>3,768</td>
<td>3,833</td>
<td>3,891</td>
<td>4,013</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31,900</strong></td>
<td><strong>33,900</strong></td>
<td><strong>38,100</strong></td>
<td><strong>39,600</strong></td>
<td><strong>37,300</strong></td>
</tr>
</tbody>
</table>


Figure 3  Global share of primary aluminium production 2005-2009

Following the economic recession the global production of primary aluminium declined in 2009. However, the following year the global production of primary aluminium recovered to 41.7 million metric tonnes in 2010 (USGS, 2011). Interestingly, this increase in the global production resulted from the construction of new smelters and the re-starting of smelters shut down during the recession primarily from countries such as China and the United Arab Emirates. This trend is clearly illustrated in Figure 4 with China’s production increasing sharply from 12.9 million metric tonnes in 2009 to an estimated 16.8 million metric tonnes in 2010. The production of primary aluminium also increased significantly in the United Arab Emirates from 0.75 million metric tonnes in 2005 to an estimated 1.4 million metric tonnes in 2010.

Figure 4  Development of primary aluminium production and capacity between 2005-2010

<table>
<thead>
<tr>
<th>Year</th>
<th>EU27</th>
<th>China</th>
<th>USA</th>
<th>Norway</th>
<th>Russian Federation</th>
<th>United Arab Emirates</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>2006</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>2007</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>2008</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>2009</td>
<td>6,000</td>
<td>6,000</td>
<td>6,000</td>
<td>6,000</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>2010</td>
<td>7,000</td>
<td>7,000</td>
<td>7,000</td>
<td>7,000</td>
<td>7,000</td>
<td>7,000</td>
</tr>
</tbody>
</table>

Note: Production capacity information unavailable from the USGS for the EU27, only incomplete country specific data for the region available (i.e. Germany)


The extent to which this global increase in primary aluminium production is based upon existing capacity or from new investments may have considerable implications for the competitiveness of producers in developed countries. For example, China and the United Arab Emirates have significantly expanded their capacity during the period 2005-2010 and are also associated with high capacity utilisation rates. In contrast, countries such as Norway and the USA have experienced a decline in capacity utilisation of 34% and 13% respectively during the same period in addition to a slight capacity decline (USGS Mineral Commodity Summaries, 2011).
Although the capacity data for the EU27 is not available from the USGS Mineral Commodity Summaries; information is available for the Member State of Germany. Similarly to both the USA and Norway, the capacity utilisation of Germany declined considerably (i.e. from 100% in 2005 to 60% in 2010) in addition to a slight decline in capacity (i.e. 0.67 million metric tonnes in 2005 to 0.62 million metric tonnes in 2010). It is evident from Figure 4 that investment in additional production capacity in Europe and the USA has been limited over the last five years; however the reasons underlying this trend are complex with the price and length of electricity contracts and projections for overall economic development being important factors influencing investment decisions.

3.2.2. Secondary aluminium production output

The production of secondary aluminium is dependent upon the recycling of metal, and the recycling rate has considerably increased in recent years for all of the main aluminium producing countries or regions. The USA is associated with a high rate of aluminium recycling and this is reflected by the high proportion of aluminium produced in the country via the secondary route (i.e. 2.7 million metric tonnes in 2009). The EU27 is also associated with a high level of secondary aluminium production, which may even be underestimated by USGS. The production of secondary aluminium has increased by approximately 60% in China between 2005 and 2009. This increase in secondary production has been facilitated by an improvement in the level of recycling with about 1.3 million metric tonnes of the secondary aluminium produced in 2009 originating from domestic sources of old and new scrap (USGS, 2010b). However the majority of the secondary aluminium produced in 2009 was dependent upon the import of aluminium scrap from other countries. The increasing demand of China for aluminium scrap is becoming a contentious issue within the sector (Figure 5).

<table>
<thead>
<tr>
<th></th>
<th>2005 ['000 metric tonnes]</th>
<th>2006 ['000 metric tonnes]</th>
<th>2007 ['000 metric tonnes]</th>
<th>2008 ['000 metric tonnes]</th>
<th>2009 ['000 metric tonnes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU27</td>
<td>2,679</td>
<td>2,944</td>
<td>3,041</td>
<td>2,847</td>
<td>2,234</td>
</tr>
<tr>
<td>China</td>
<td>1,940</td>
<td>2,350</td>
<td>2,750</td>
<td>2,700</td>
<td>3,100</td>
</tr>
<tr>
<td>USA</td>
<td>3,030</td>
<td>3,540</td>
<td>3,790</td>
<td>3,330</td>
<td>2,710</td>
</tr>
<tr>
<td>Norway</td>
<td>362</td>
<td>349</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Australia</td>
<td>127</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Canada</td>
<td>48</td>
<td>47</td>
<td>50</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Brazil</td>
<td>251</td>
<td>253</td>
<td>255</td>
<td>292</td>
<td>273</td>
</tr>
<tr>
<td>Japan</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Mexico</td>
<td>574</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
</tbody>
</table>

Note: According to the EAA (2011) production of recycled aluminium in Europe is 4.7 million tonnes in 2008; it is possible that the USGS data refers only to refining as secondary aluminium production.

3.3. Emissions

3.3.1. Emissions from primary aluminium production

The production of primary aluminium is associated with CO$_2$ emissions from both direct and indirect sources. Direct CO$_2$ emissions are caused by the manufacture and use of carbon anodes during the smelting process. PFC emissions are caused by anode effects during the production of primary aluminium in the smelting process. Indirect CO$_2$ emissions result from the use of the electricity required for the production of primary aluminium. All of these sources of emissions are represented in Figure 6 as bars for the key aluminium producing countries or regions. In addition, the lines in Figure 6 illustrate the total specific emissions of primary aluminium production.

The majority of emissions in the production of primary aluminium originate from indirect sources, which reflects the high electricity consumption associated with the smelting process. China had the highest specific emissions of 13.4 t CO$_2$eq/ t for the primary production of aluminium in 2008, mainly because of the carbon content of their electricity generation. In addition, PFC emissions were relatively high compared to the EU27 and the USA due to the use of outdated technology. In the EU27, specific emissions from aluminium production are about 9.1 t CO$_2$eq per tonne of product. It is important to acknowledge that the specific emissions were very low in Norway due to extensive hydro power availability in the country for electricity generation.
3.3.2. Emissions from secondary aluminium production

In contrast to the primary production route, the production and subsequent electrolysis of alumina is not necessary to produce aluminium; therefore the emissions associated with the production of secondary aluminium are considerably lower. ‘Secondary smelting of aluminium using scrap only requires roughly 5% of the energy of primary smelting due to the relatively low melting temperature of 700-800 °C’ (Worrell et al 2007). The emissions resulting from the process will vary from country to country depending upon the level of secondary aluminium production, fuel input for and the efficiency of the technology deployed to recycle the aluminium scrap (i.e. reverberatory and induction furnaces). Unfortunately consistent data on emissions from secondary aluminium production by country or region were not currently accessible.
4. Trade flow analysis

The following section provides insights into the flow of aluminium products between countries and differentiated by product during the time period 2005-2010 with a particular focus on EU27 trade. Firstly, the extent to which the EU27 imports or exports aluminium products (i.e. the trade balance) is quantified to determine whether the region is a net importer or exporter. Secondly, the main export destinations of the EU27 for aluminium products are outlined and third countries that compete with the EU27 on these export markets are subsequently identified. Thirdly, the imports to and exports from the EU27 are determined for the region’s main export destinations and this trade is differentiated by product.

4.1. Trade flow differentiated by product

4.1.1. Aluminium by product

An overview of the trade balance of the EU27 for aluminium products with the rest of the world is provided in Figure 7. Firstly, it is evident that in terms of trade value, the EU27 exports considerably less aluminium products than it imports. On average the EU27 annually imported aluminium products valued at $18 billion; however the average value of EU27 annual exports were valued at only $8 billion. The 2005-2010 time series also demonstrates the impact of the global economic recession on the import to and export from the EU27 of aluminium products, with a sharp decline in trade volume evident in 2009, followed by an initial recovery in trade volume in 2010.

When individual products within the aluminium sector are considered, it is evident that the majority of the trade value of aluminium imports is associated with products that are lower down the value chain. For example, unwrought aluminium ($11.3 billion) represented the majority (63%) of the trade value of EU27 imports between the years 2005 and 2010. In addition, annual imports of aluminium oxide to the EU27 were valued at $609 million on average between 2005 and 2010. In contrast, EU27 exports of aluminium are predominately of higher value with further rolling or extrusion processing steps required to manufacture the semi-fabricated products. For example, aluminium plates ($2.9 billion) accounted for (34%) of the trade value of EU27 exports between the years 2005 and 2010.
Figure 7  Trade value of aluminium imports to the EU27 between the years 2005 and 2010

Note: The average trade value of exports between 2005 and 2010 include the following HS categories: 262040, 281820, 7601, 7602, 7603, 7604, 7605, 7606, 7607, 7608, and 7609.

Source: UN COMTRADE (2011), processed by Öko-Institut (2011)

4.2. Trade flow differentiated by country /region

In order to determine the extent to which third countries compete with the EU27 on aluminium export markets it is necessary to first distinguish between direct and indirect trading partners of the EU27. A direct (indirect) trading partner refers to a country that either imports from or exports to the EU27 (direct trading partner). The following section provides a trade flow analysis differentiated by country or region whereby the direct and indirect trading partners with the EU27 for aluminium products can be identified from Table 4. The columns in Table 4 refer to the average annual trade value (2005-2010) of the EU27 and its’ direct trading partners imports. The rows in Table 4 refer to the average annual trade value (2005-2010) of a country’s or region’s exports to the EU27 and its’ direct trading partners. The focus of this analysis is on the export of EU27 aluminium products and therefore the indirect trading partners of the EU27 are identified for the region’s main export destinations.

On average the EU27 imported aluminium products with a trade value of approximately $18 billion between 2005 and 2010. Figure 8 shows that Norway accounted for the largest share of this...
imported trade value of aluminium products ($4.7 billion) followed by the Russian Federation ($2.3 billion), Mozambique ($1.2 billion), the USA ($0.6 billion) and China ($0.5 billion). The main export destinations of aluminium products (2005-2010 average) from the EU27 include the USA, Switzerland, China and the Russian Federation. In the import market of these four countries, the EU27 accounted for 68% of Switzerland’s aluminium imports followed by the Russian Federation (20%), China (15%) and the USA (9%). An indirect trading partner of the EU27 refers to a country that either imports from or exports to a direct trading partner of the EU27. Important indirect trading partners are identified in Figure 8 for the main export destinations of the EU27.

Table 4  Average trade value of aluminium imported to the USA, Switzerland, China, Russian Federation and EU27 between 2005 and 2010

<table>
<thead>
<tr>
<th>Exporters</th>
<th>USA</th>
<th>Switzerland</th>
<th>China</th>
<th>Russian Federation</th>
<th>EU27</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>795.16</td>
<td>7.71</td>
<td>--</td>
<td>61.74</td>
<td>532.05</td>
</tr>
<tr>
<td>USA</td>
<td>7.14</td>
<td>7.77</td>
<td>905.06</td>
<td>14.06</td>
<td>635.87</td>
</tr>
<tr>
<td>Norway</td>
<td>8.44</td>
<td>74.40</td>
<td>23.61</td>
<td>5.51</td>
<td>4,697.26</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>1,253.97</td>
<td>45.53</td>
<td>198.06</td>
<td>--</td>
<td>2,347.26</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>220.87</td>
<td>0.36</td>
<td>92.20</td>
<td>0.77</td>
<td>454.23</td>
</tr>
<tr>
<td>Iceland</td>
<td>2.40</td>
<td>47.61</td>
<td>1.97</td>
<td>0.00</td>
<td>1,183.98</td>
</tr>
<tr>
<td>South Africa</td>
<td>271.03</td>
<td>51.91</td>
<td>94.39</td>
<td>3.37</td>
<td>328.11</td>
</tr>
<tr>
<td>Australia</td>
<td>364.72</td>
<td>0.01</td>
<td>2,034.41</td>
<td>327.53</td>
<td>67.47</td>
</tr>
<tr>
<td>Canada</td>
<td>7,271.30</td>
<td>13.37</td>
<td>74.47</td>
<td>0.25</td>
<td>435.97</td>
</tr>
<tr>
<td>India</td>
<td>75.40</td>
<td>0.13</td>
<td>267.10</td>
<td>1.59</td>
<td>84.51</td>
</tr>
<tr>
<td>Brazil</td>
<td>451.18</td>
<td>164.56</td>
<td>52.83</td>
<td>7.99</td>
<td>734.32</td>
</tr>
<tr>
<td>Rep. Of Korea</td>
<td>51.72</td>
<td>0.22</td>
<td>811.16</td>
<td>2.78</td>
<td>30.97</td>
</tr>
<tr>
<td>Mozambique</td>
<td>2.96</td>
<td>--</td>
<td>10.85</td>
<td>--</td>
<td>1,208.70</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>--</td>
<td>1.26</td>
<td>30.74</td>
<td>434.68</td>
<td>12.46</td>
</tr>
<tr>
<td>Japan</td>
<td>144.47</td>
<td>2.72</td>
<td>693.14</td>
<td>4.57</td>
<td>89.93</td>
</tr>
<tr>
<td>EU27</td>
<td>1,275.08</td>
<td>1,029.72</td>
<td>1,285.02</td>
<td>416.90</td>
<td>--</td>
</tr>
<tr>
<td>Non EU27</td>
<td>12,704.19</td>
<td>485.68</td>
<td>7,276.64</td>
<td>1,634.40</td>
<td>17,962.01</td>
</tr>
<tr>
<td>Total</td>
<td>13,979.26</td>
<td>1,515.41</td>
<td>8,561.67</td>
<td>2,051.31</td>
<td>17,962.01</td>
</tr>
</tbody>
</table>

Note: The average trade value of imports between 2005 and 2010 include the following HS categories: 262040, 281820, 7601, 7602, 7603, 7604, 7605, 7606, 7607, 7608, and 7609.

Source: UN COMTRADE (2011), processed by Öko-Institut (2011)

The role of Canada as an indirect trading partner in the financially important US market is clearly demonstrated in Figure 8. Canada has the majority share of the US market (52%) which equates to approximately $7 billion in annual export value on average between the years 2005 and 2010. As an indirect trading partner China accounts for a 6% share in the US market, this is equivalent to an annual export value of $0.8 billion. The EU27 has the fourth largest market share of aluminium product imports into the US market followed by the Russian Federation (9%). Given the geographical proximity of Switzerland to Europe, it is to be expected that the EU27 accounts for the majority of the country’s aluminium product imports. However, interestingly the trade flow analysis demonstrates that Brazil has emerged as the main competitor to the EU27 dominance with a market share of 11%, which is equivalent to $165 million in annual export value on average between 2005 and 2010 (Figure 8).
In the Chinese market for aluminium products, it is evident from Figure 8 that Australia is an important indirect trading partner with a market share of 24%, which results in average annual export value of approximately $2 billion between 2005 and 2010. Imports from the EU27 represent the second largest share of the Chinese market, followed by imports from the USA (11%), the Republic of Korea (9%) and Japan (8%). Aluminium product imports from the EU27 account for the largest share of the Russian Federation market. Kazakhstan represents an important indirect trading partner on the Russian market with a market share of 21%, which is equivalent to $435 million in annual export value on average between the years 2005 and 2010.

Figure 8 Average trade value of aluminium imported to the USA, Switzerland, China, Russian Federation and EU27 between 2005 and 2010

Note: The average trade value of imports between 2005 and 2010 include the following HS categories: 262040, 281820, 7601, 7602, 7603, 7604, 7605, 7606, 7607, 7608, and 7609.

Source: UN COMTRADE (2011), processed by Öko-Institut (2011)
4.3. Trade flow differentiated by product by third country

4.3.1. Aluminium by product by third country

The trade value relationship in US$ between imports to and exports from the EU27 for the important trading partners previously identified is outlined in Figure 9. From the perspective of imported aluminium products, it is evident from Figure 9 that the EU27 imports unwrought aluminium mainly from Norway and the Russian Federation. Indeed unwrought aluminium accounts for 82% and 76% of all aluminium product imports from Norway and the Russian Federation respectively to the EU27 between the years 2005 and 2010. Interestingly the EU27 also imports aluminium oxide from the USA, which is associated with an annual trade value of $83 million on average between 2005 and 2010.

With regards to exported aluminium products, it is evident from Figure 9 that the EU27 exports predominantly higher value products. For example, aluminium plates and aluminium foil accounted for 52% and 23% of the trade value of the aluminium products exported from the EU27 to the USA between 2005 and 2010. Both products are associated with additional process steps and are higher up the value chain. Aluminium plate also accounted for a considerable share (26%) of EU27 exports to China (Figure 9). However, interestingly the EU27 also exported lower value aluminium scrap to China, which was valued at approximately $570 million annually on average between the years 2005 to 2010.
Figure 9: Average trade value of aluminium imports to and aluminium exports from the EU27 between 2005 and 2010 and recovered paper for the four main export destinations

Note: The average trade value of exports between 2005 and 2010 include the following HS categories: 262040, 281820, 7601, 7602, 7603, 7604, 7605, 7606, 7607, 7608, and 7609.

Source: UN COMTRADE (2010), processed by Öko-Institut (2011)
5. Carbon leakage analysis

5.1. Assessment of carbon leakage at the sector level

The allocation of free allowances to sectors ‘deemed to be exposed to a significant risk of carbon leakage’ provides some reassurance to installations within the EU ETS that their participation in the scheme will not result in a loss in competitiveness due to the introduction of carbon costs. According to Article 10a of the revised EU ETS Directive (2009/29/EC) a sector or sub-sector is deemed to be exposed to a significant risk of carbon leakage if:

- the extent to which the sum of direct and indirect additional costs induced by the implementation of this directive would lead to a substantial increase of production cost, calculated as a proportion of the Gross Value Added, of at least 5%; and
- the Non-EU Trade intensity defined as the ratio between total of value of exports to non-EU + value of imports from non-EU and the total market size for the Community (annual turnover plus total imports) is above 10%.

A sector or sub-sector is also deemed to be exposed to a significant risk of carbon leakage if:

- if the sum of direct and indirect additional costs induced by the implementation of this directive would lead to a particularly high increase of production cost, calculated as a proportion of the Gross Value Added, of at least 30%; or
- if the Non-EU Trade intensity defined as the ratio between total of value of exports to non-EU + value of imports from non-EU and the total market size for the Community (annual turnover plus total imports) is above 30%.

These criteria were applied at the sector or sub-sector level to assess the risk of carbon leakage for European industry with the outcome of the assessment adopted by the European Commission in December 2009. Based upon the criteria used in the carbon leakage assessment, 77% of the covered ETS emissions from manufacturing are classified as being at ‘risk of carbon leakage (COM, 2011a). The aluminium sector is included within the carbon leakage list, as the assessment calculated a trade intensity of 36% and a CO\textsubscript{2} cost as a proportion of GVA of 15% both exceeded the threshold criteria. Aluminium firms are therefore eligible for free allowances in Phase III of the EU ETS, which will be allocated based on two product benchmarks with the remaining products covered by fall back options (i.e. measurable heat, fuel input).

The carbon leakage assessment demonstrates that the aluminium sector is trade intensive; however the carbon cost associated with aluminium production is considerably lower than the carbon costs associated with other sectors such as the production of fertilizers or cement (Figure 10). Given that the carbon leakage assessment considers both direct and indirect emissions; the impact of higher electricity prices in Phase III of the EU ETS is already reflected in the outcome of the assessment.
Table 5  Product benchmarks for allocation of free allowances in the EU ETS

<table>
<thead>
<tr>
<th>Product</th>
<th>Benchmark [allowances/tonne]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-bake anode</td>
<td>0.324</td>
</tr>
<tr>
<td>Unwrought non-alloy aluminium (excluding powders and flakes)</td>
<td>1.514</td>
</tr>
</tbody>
</table>

Source: COM (2011b)

Figure 10  Outcome of the carbon leakage assessment adopted by the Commission in 2009

Source: COM (2009); Öko Institut Calculation (2011)
5.2. Trade intensity and emission benchmarks for aluminium products

The following exercise attempts to expand upon the carbon leakage assessment by calculating the trade intensity of various aluminium products using the PRODCOM database for production and related trade data. The added value of such an exercise is to focus attention on a subset of aluminium products with trade intensities that are considerably higher or lower than the sector level average. If CO₂ emissions data were available at the product level, it would then be possible to determine whether or not these trade intensive aluminium products were also CO₂ intensive and therefore potentially exposed to the risk of carbon leakage. Given that GVA and CO₂ emissions data are not currently available at the product level, the following exercise refers only to product benchmarks in order to illustrate how the trade intensity and CO₂ intensity of aluminium products may vary.

The trade intensity for aluminium products in the EU27 is illustrated in Figure 11. Aluminium products from the lower part of the value chain are generally associated with high trade intensities that considerably exceed the 30% threshold used in the carbon leakage assessment by the Commission. For example, the trade intensity of aluminium oxide was on average 48% between 2006 and 2009, which accounted for the highest trade intensity of all the aluminium products considered in the exercise. Given that the production of aluminium oxide is associated with direct CO₂ emissions from the digestion and calcination steps, it is envisaged that CO₂ pricing may place European firms at a competitive disadvantage resulting in carbon leakage. The annual trade intensity of unwrought aluminium was on average 45% between 2006 and 2009. It is important to acknowledge that unwrought aluminium is an aggregate value for three PRODCOM codes (i.e. unwrought non-alloy aluminium, unwrought alloy aluminium in primary form and unwrought alloy aluminium in secondary form), which are characterized by considerable differences in both trade intensity and specific emission best practice benchmarks.

Unwrought non-alloy aluminium (i.e. primary aluminium) was associated with an average trade intensity of 79% between 2006 and 2009. Based upon the product benchmark in Table 5 it is evident that this product has a high CO₂ intensity with direct emissions of 1514 kg CO₂/t. The product benchmark reflects the fact that the reduction of alumina to aluminium via electrolysis represents the most energy intensive step of the process to produce primary aluminium. In addition, given the indirect emissions from the consumption of electricity in the smelting process, it is likely that the production of unwrought non-alloy aluminium may be particularly vulnerable to increased direct and indirect carbon costs and therefore carbon leakage.

In contrast, the trade intensity of unwrought alloy aluminium in secondary form (i.e. secondary aluminium) was on average only 10% during the same period. The specific emissions best practice benchmark of 220 kg CO₂/t for secondary aluminium (Ecofys et al., 2009) is also considerably lower than the product benchmark assigned to the primary production of aluminium. Given that the trade intensity and specific emission benchmark are relatively low for secondary aluminium compared to other aluminium products it is likely that this product is less vulnerable to the risk of carbon leakage.
Aluminium products from the higher part of the value chain (i.e. aluminium wire, plates, foil and tube and piping) are also associated with trade intensities that exceed the 30% threshold (Figure 11). However, the emission intensity of these products is considerably lower than for intermediate aluminium products (i.e. aluminium oxide, unwrought aluminium). For example, direct emissions from the rolling and extrusion process typically range from 20-235 kg CO$_2$/t and 50-170 kg CO$_2$/t respectively (Ecofys et al., 2009). Although these products are highly traded, specific emissions are relatively low and it is also conceivable that product specialisation further reduces the risk of carbon leakage for these aluminium products from the higher part of the value chain.
6. Summary and Discussion

An overview of the production processes, output and emissions associated with the aluminium sector were provided in this paper and the following key findings are outlined in the bullet points below:

- Production routes for aluminium vary between primary and secondary, both of which require different raw material inputs. Primary aluminium production requires the reduction of alumina via the electrolysis process. Secondary aluminium production is dependent upon the use of old and new scrap, which are subsequently remelted and refined. The production of primary aluminium is associated with higher specific emissions than the alternative secondary route.

- Global aluminium production is growing again after the recession. The countries driving this global growth appear to be from China and the Middle East, where investments are resulting in increased primary production capacities. In contrast, the EU27 and the USA have seen their share in the global production of primary aluminium decline between 2005 and 2009. However both regions are associated with high recycling rates for secondary aluminium production.

The trend of increasing capacity in the production of primary aluminium for both China and the United Arab Emirates between 2005 and 2010 suggests that investments are increasingly ‘flowing to locations that can offer long-term energy contracts’ (Rademaekers et al, 2011). The availability of such long-term energy contracts is often associated with countries with a non-liberalised energy market where there is (partial) state ownership in energy generation and supply installations. It is conceivable that energy prices may be subsidised in certain third countries to encourage further investment in their production capacity. According to Rademaekers et al. (2011) the importance of being able to access a secure electricity supply is also encouraging many aluminium producers (i.e. BHP Billiton) to consider the availability of stranded power generation (i.e. without transmission links) as part of their aluminium smelter strategy.

The combination of high electricity prices and shorter term energy contracts in Europe in addition to the economic recession may have contributed to a decline in the region’s global share of primary aluminium production between 2005 and 2009. The introduction of the EU ETS (i.e. pass through costs of emission allowances) and the partial liberalisation of the energy market in Europe (i.e. marginal pricing system) have increased the price of electricity and added to the complexity of negotiating energy contracts. However, it needs to be noted that it is not possible to disentangle the effect of higher electricity prices from the effects of the economic recession. In this context it can be observed that the USA’s global share of aluminium production also declined between 2005 and 2009 even though the country has not introduced carbon pricing pointing more to an effect of the economic development. Other factors in the cost structure of aluminium production (i.e. raw materials, labour costs) may also have an influence on production decisions. The extent to which the EU ETS impacts the electricity price is beyond the scope of this paper and further research is therefore required to decompose the causes of changes in production and thereby to contribute to the ongoing discussion on the need for compensatory mechanisms in the aluminium industry to offset the CO₂ cost pass through in electricity prices.

An analysis of the trade flow of aluminium between the EU27 and third countries was also outlined in the paper. Important trading relationships by country and by product were identified in
order to establish a subset of countries and aluminium products that require special consideration in the carbon leakage debate. Key findings include:

- The main export destinations of the EU27 are the USA, Switzerland, China and the Russian Federation. Indirect trading partners have been identified in each of these four markets. Canada (Australia) has a strong trading relationship with the USA (China). Brazil (Kazakhstan) has emerged as a competitor in the Swiss (Russian) market.
- The EU27 imports considerably more aluminium products, especially those lower down the value chain, than the region exports to world markets. The import market of the EU27 was severely affected by the economic recession.
- Norway and the Russian Federation have been identified as important trading partners for the import of the unwrought aluminium product. The EU27 exports aluminium plate and foil to the more lucrative US and Chinese markets. However, interestingly the EU27 also exports aluminium scrap to China.

Given the competitive advantage of certain third countries that benefit from low energy costs, the EU27 is increasingly importing lower value aluminium products from these regions. As a response to this greater dependence on third countries for primary aluminium products, the EU27 has improved the capacity to recycle aluminium and is now considered one of the most advanced regions for recycling in the world. However, despite the high recycling rate and demand for aluminium scrap in the EU27, the trade flow analysis shows that the region continues to export aluminium scrap to China. The price of aluminium scrap has increased in response to the high demand from China and the export restriction on raw materials by supplying countries (i.e. Russia) incentivising the export of aluminium scrap from the EU27 to China (Rademaekers et al, 2011). The trade of aluminium scrap remains a particularly contentious issue for the aluminium industry.

An explanation of the relevance of the carbon leakage assessment conducted by the European Commission to the aluminium sector was provided in the paper. In addition, production, trade and emission benchmark data was analysed at the disaggregated product level to provide further insights into the carbon leakage risk of aluminium products.

- Based upon the criteria used in the carbon leakage assessment, the aluminium sector is exposed to the risk of carbon leakage. The analysis of trade intensity at the product level confirmed that the majority of aluminium products exceed the absolute threshold of 30% trade intensity. However, the specific emission benchmarks of these products varied considerably across the value chain.
- Unwrought aluminium is a product that may be particularly exposed to carbon leakage due to its’ high trade and CO$_2$ intensity benchmark. Equally the low trade intensity and CO$_2$ intensity of secondary aluminium is less of a concern for carbon leakage. Although semi-fabricated aluminium products are also associated with high trade intensities it is expected that the risk of carbon leakage is lower due to the low range of direct emissions and product specialisation.

The paper contributes to the on-going carbon leakage discussion in the aluminium sector with the provision of a subset of countries and products that require special consideration in future research. The import of unwrought aluminium by the EU27 from both Norwegian and Russian trading partners demonstrates the value of such an analysis. The import of this energy intensive product from outside the EU27 will only result in carbon leakage if the unwrought aluminium
originates from the Russian Federation. This is due to the fact that Norway is a member of the EU ETS and has access to low carbon electricity. In contrast, the carbon content of electricity in the Russian Federation is considerably higher and therefore carbon leakage is potentially an issue that needs to be resolved. The identification of countries and products of interest will allow for more considered policy measures to address carbon leakage risks.

The assessment of the sector’s exposure to carbon leakage is limited by data constraints at the product level with regard to GVA and emissions data. It is acknowledged that the use of emission benchmarks fails to represent actual emissions and therefore the potential cost of carbon pricing for aluminium firms. However, the aim of this paper is to focus attention on where different datasets can improve our understanding of the carbon leakage risk. Indeed, it is evident from the analysis in this paper that actual emissions data at the product level is urgently required to complete a comprehensive assessment of the competitiveness issues associated with carbon pricing.
7. References:


Rademaekers K et al. (2011): Competitiveness of the EU Non-ferrous Metals Industries. FWC Sector Competitiveness Studies. Final Report


Climate Strategies is an international organisation that convenes networks of leading academic experts around specific climate change policy challenges. From this it offers rigorous, independent research to governments and the full range of stakeholders, in Europe and beyond.

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